Renewable and Sustainable Energy Reviews 33 (2014) 353–362

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy models from a strategic environmental assessment perspective in an EU context—What is missing concerning renewables?

Xi Pang*, Ulla Mörtberg, Nils Brown

KTH Royal Institute of Technology, Department of Sustainable Development, Environmental Science and Engineering, Brinellvägen 28, SE-100 44 Stockholm, Sweden.

ARTICLE INFO

Article history:
Received 5 April 2013
Received in revised form
20 January 2014
Accepted 2 February 2014
Available online 4 March 2014

Keywords:
Energy models
Strategic environmental assessment
Landscape
Land use
Biodiversity
Policy assessment

ABSTRACT

Climate change and security of energy supply are main sustainability issues today and an energy systems shift towards renewable energy sources is therefore urgent. However, unless environmental impacts of such a shift are carefully taken into account, imposed resource and land use changes may counteract other sustainability goals, such as preserving biodiversity and ecosystem services. Strategic Environmental Assessment (SEA) provides a comprehensive framework for assessment of policies and plans where a full range of environmental issues are addressed. The aim of this article was to find possibilities for comprehensive sustainability assessment among published energy–environment models and the linking of renewable energy analysis to landscape and biodiversity issues through land use concerns. Based on the review of relevant energy, environmental and linking models, a survey on publications and a case study on the EU Energy Roadmap 2050, the results show that existing energy models and research have low concerns on land use, landscapes and biodiversity. Consequently, it would be difficult to provide comprehensive decision support by using only these tools. However, suitable energy models, ecological assessment models and multi-criteria approaches exist with great potential for inter-linking. The development of energy models could thus have new orientations, connecting them to involve renewable energy options with land use, landscape and biodiversity concerns, which could be advanced into powerful SEA tools for integrated policy assessment. This will enable the development of more comprehensive decision support tools for assessing future energy scenarios, integrating main policy concerns when assessing renewable energy options.

Contents

* Corresponding author. Tel./fax: +0046 08 790 7378.
E-mail address: xip@kth.se (X. Pang).

http://dx.doi.org/10.1016/j.rser.2014.02.005
1364-0321

1. Introduction

Climate change and security of energy supply are main sustainability issues today and an energy systems shift towards renewable energy sources is therefore urgent. However, unless environmental impacts of such a shift are carefully taken into account, imposed resource and land use changes may counteract other sustainability goals, such as preserving biodiversity and ecosystem services (e.g. [1–6]). Since both climate change and biodiversity are increasingly seen as being of highest priority [7,8], there is a need for an integrated approach for addressing these issues that can take both energy and environmental impacts into account.

To counteract climate change by reducing greenhouse gas emissions and to promote security of energy supply, increased use of energy from renewable sources is an important part of the measures needed, which is supported by e.g. the EU Renewable Energy Directive (2009/28/EC). With a view of achieving the commitment within EU of reducing greenhouse gas emissions to 80–95% below 1990 levels by 2050, several scenarios have been built and analysed in order to explore the challenges and opportunities of possible future development alternatives. Firstly, in the Roadmap for moving to a competitive low-carbon economy in 2050 [9], the implications of this commitment were analysed. This Roadmap seeks to develop a long-term European technology-neutral policy framework to modernize energy supply. Secondly, in the Energy Roadmap 2050 [10], according to the scenario analyses, a secure, competitive and decarbonized energy system in 2050 is possible. On the way to this goal, the energy system would be transforming together with a number of structural changes, such as decarbonisation of the energy system, a substantial rise of renewables, energy savings, and other. In all scenarios, which were built on different combinations of these structural changes, the share of renewable energy sources would rise substantially, achieving at least 55% in gross final energy consumption in 2050 [10].

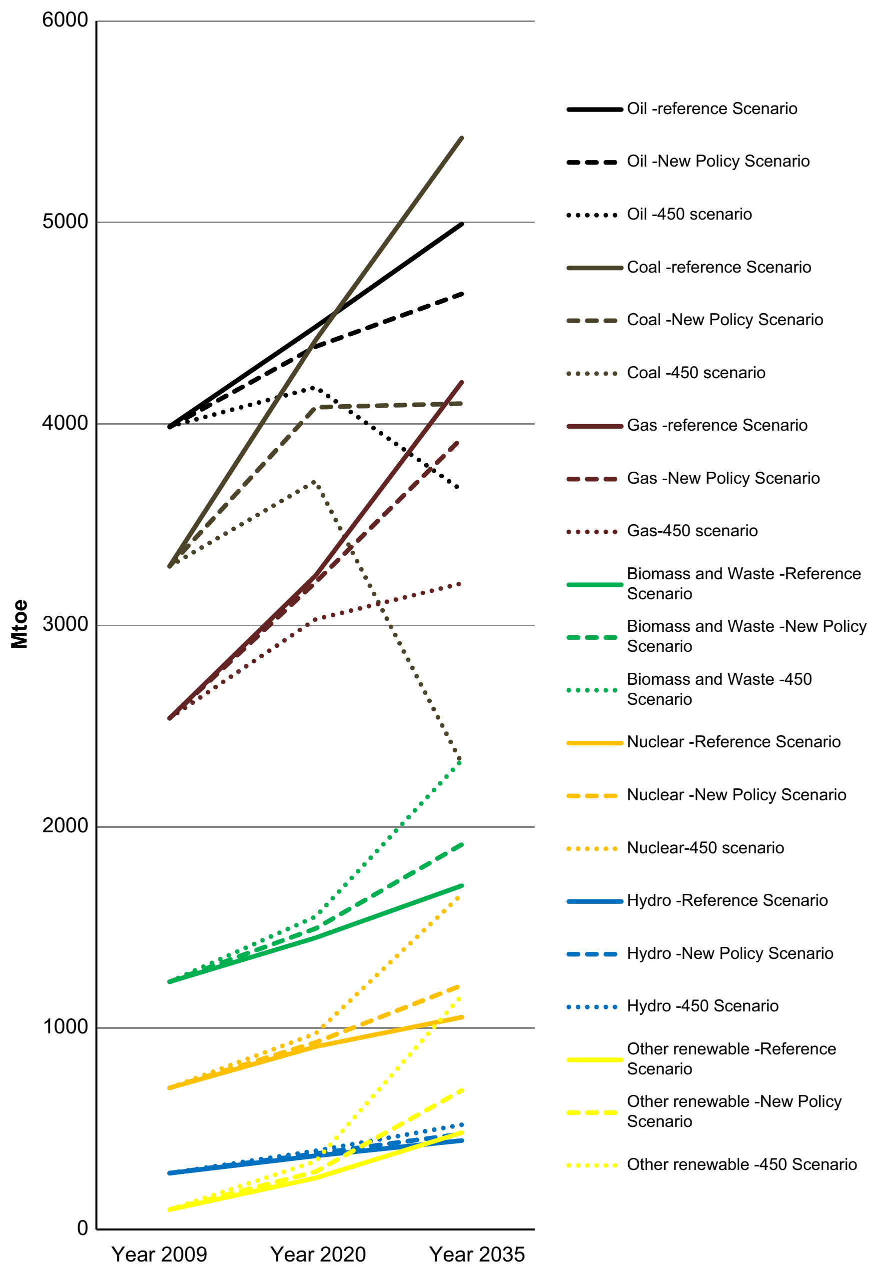


Fig. 1. Energy demand projected by World Energy Outlook 2011 (International Energy Agency [12]).

According to the EU Energy Roadmap 2050, renewables will become a central part of the energy mix in Europe, moving "… from technology development to mass production and deployment, from small-scale to larger-scale, integrating local and more remote sources, from subsidized to competitive…" [10]. In particular, wind power would provide more electricity than any other technology in the High Renewables scenario by 2050, and solar power could, with further technological development, deliver substantial quantities of electricity for e.g. Mediterranean countries. Biomass for heat, electricity and transport would be largely demanded for decarbonisation, while the role of hydropower was considered to be relatively stable in all scenarios [11]. Projections of energy demand have been done by World Energy Outlook 2011 [12]. As shown in Fig. 1, renewable energy demand will increase significantly in the low carbon scenario, as replacement for fossil energy.

The land use changes imposed by the shift towards more renewable energy options and the related infrastructure can, when implemented on large scale, be foreseen to have significant impacts on landscapes and environment. This can rise critical questions concerning whether renewables can really insure a sustainable development.

In line with such discussions, the environmental impacts of the EU Energy Roadmap 2050 were assessed by the EC [11], who concluded that all decarbonisation scenarios would achieve 80% greenhouse gas reduction and close to 85% energy related CO_2 reduction in 2050. In most scenarios, air pollution can be expected to decrease, while all options would impact on land use. These land use changes, caused by grid development, power plant installation and operation, renewable infrastructure and biomass extraction from forestry and agriculture, will have negative impacts on biodiversity and ecosystems services, while the impacts on water systems will depend on the energy mix.

1.1. Environmental impacts of renewable energy technology

The different renewable energy technologies and the related plantations (forest and agricultural crops) and infrastructure (wind mills, solar farms, dams, access roads, grids, etc.) have different specific environmental impacts which only recently have been studied.

Wind power plants and access roads affect wildlife and thus biodiversity through collisions, habitat loss, fragmentation and degradation [13–17]. The typical turbine foundation affects 0.08–0.2 ha and may crush underground wildlife at depth of up to 60 cm ([13,17]). The estimated area requirement for a wind farm of 1 MW is 1600–6000 m^2 [16], which together with the roads constructed for access to wind farms, impose high risk for impacts such as habitat degradation, fragmentation and loss. Similarly, monopoles of offshore turbines may lead to loss of large areas of sea bed habitat, and thus affecting marine wildlife. In addition, wind power plants affect landscapes and related cultural ecosystem services, through habitat changes, visual impacts and noise (e.g. [18]). Meanwhile, impacts due to vibration, electromagnetic field generation are still not clear.

Impacts of *solar energy* follow similar patterns as wind farms due to large land occupation to harness sunlight [19,20]. In addition, wet-cooling solar systems consume large amounts of water [21], with temperatures in the most concentrated solar systems reaching 300 °C; there is a potential risk of hazardous chemical spill and the fire risk can be high [22].

Environmental impacts of *bioenergy generation* differ widely, depending on e.g. raw materials (crops, forest biomass, and waste), producing techniques, geological differences and analysis methods [23–25]. Combustion air pollution, land use competition and biodiversity impacts are critical environmental issues related to energy crop plantations [26–28]. Forest bioenergy is closely linked with forest biodiversity and ecosystem services, both on local and landscape levels, and the impacts have widely been seen as problematic, negative [29,30,31], or in need of further research [32]. Other environmental impacts such as acidification and eutrophication are related to some bioenergy options [33,34]. Even the 'carbon-neutral' property of bioenergy, making it attractive for climate change mitigation, has been questioned by some studies (e.g. [23,24,35]).

Hydropower plants and related water reservoirs strongly affects ecosystems of lakes and watercourses as well as shorelines (e.g. [36–38]). Directly, dams can result in barrier functions for migration of fish and other aquatic species; upstream impacts would have effects on invertebrates, fish, birds, mammals and growth of macrophytes in reservoirs. Furthermore, sediment transport, annual flow regimes and water quality will also be affected with major consequences for downstream ecosystems. Indirectly, impacts can be anticipated also on adjacent ecosystems, such as riparian zones and wetlands [39]. Furthermore, water reservoirs for hydropower have been seen as significant sources of GHG emissions due to the CO_2 and CH_4 released from decaying vegetation [27,36].

Thus renewables on large scales, especially wind power, solar power and bioenergy, need or affect large land areas for plantations and infrastructure; while hydropower impacts on water ecosystems. Thus, natural habitats and agricultural land might be replaced or affected directly and indirectly by such plantations and infrastructure, with negative environmental impacts on, among other, biodiversity and ecosystem services (e.g. [13,19,26,27,39–42]). This means that implementing renewables on large scale may conflict with other sustainability objectives and related legislation, such as designated habitats and species protected by the EU Birds and Habitats Directives (79/409/EEC and 92/43/EEC), as well as the EU Water Framework Directive (2000/60/EC) and the European Landscape Convention. In addition, according to several authors [13,26,28,41,42], most of the possible environmental impacts are still missing in many impact assessments of energy options. This means that not only do we need methods and tools for assessing these impacts, but as well it is important to ensure that main policy concerns are properly addressed.

1.2. Strategic environmental assessment

A comprehensive framework for assessment of environmental impacts is provided by Strategic Environmental Assessment (SEA), which is developed for environmental impact analysis for policies, plans and programmes (e.g. [43,44]). This framework enables the inclusion of relevant environmental information into decision making. The inclusion of a wider set of factors is meant to contribute to more sustainable and effective solutions, which applies very well on the new demands on energy systems. SEA is implemented in EU legislation (2001/42/EC), addressing the assessment of the effects of certain plans and programmes on the environment. The aim with this Directive is to contribute to protection and improvement of the quality of the environment and to rational utilization of natural resources. According to the Treaty establishing the European Community, environmental protection requirements are to be integrated into EU policies and activities, in particular with a view to promoting sustainable development. Within the SEA framework, likely significant effects on the environment that are to be taken into account include, in sum, the specific issues biodiversity, population, human health, soil, water, air, climatic factors, material assets, cultural heritage, landscape and the interrelationship between the above factors.

Thus, the SEA framework takes a broad view on sustainability and includes a full range of issues of high policy priority, which makes it highly useful for a critical review of policy analysis tools, addressing sustainability issues.

The interactions between energy systems, climate and environment are of course highly complex to assess, but even if there are considerable uncertainties in such efforts, they can greatly help to evaluate policy options and to find mitigation approaches and adaption methods [45]. A range of policy analysis tools that are designed for analysing the energy system with the aim to provide decision support can be called energy models. These in general link energy supply and/or demand, some to economy and some to certain environmental impacts, especially concerning air quality and climate change evaluation [11,46–49]. A tool that can link energy systems to a broader range of environmental impacts and resource use is life cycle assessment (LCA) [23,50]. However, as found by e.g. Finnveden et al. [51], available analytical tools within the energy sector primarily cover environmental impacts related to emissions, while tools covering impacts on ecosystems and landscapes are more limited.

Simultaneously, models that are designed to address biodiversity, ecosystems and landscapes in the relation to e.g. land use change have been developed, providing a strong potential for analysing these interactions (e.g. [52–57]). Such models can be called ecological assessment models and, since they have a spatial dimension, can localise and quantify impacts of land use change, imposed by e.g. renewable energy plantations and infrastructure, on biodiversity and ecosystems on landscape and regional levels. Another family of tools that specifically address the linking of multiple and sometimes conflicting criteria in an integrated assessment can be called Multi-Criteria Analysis (MCA) tools [58–61]. These tools can be useful for overcoming energy–environmental assessment gaps concerning renewables in terms of how to link between models and how to assess results.

Since renewables affect environmental issues such as biodiversity, water, air, climate and landscapes, interactions between these and other sustainability issues needs to be studied and assessed. The potential to adequately address these issues can be seen as relatively high by using and further developing the existing assessment tools. However, these tools need to be integrated with each other in order to enable comprehensive policy assessment of renewable energy options.

1.3. Aim

The aim of this paper was to explore the potential of a broad selection of existing models and tools to address main environmental and sustainability issues related to the development of renewable energy options, from an SEA perspective in an EU context. The objectives were to provide an overview of potentially suitable models and tools through a literature review; and to assess the prospective of a broad selection of environmental-related energy models from an SEA perspective, in order to investigate how they dealt with environmental impacts and what environmental issues were addressed. By exploring the scope, abilities and linking potential of models and tools, and by identifying knowledge gaps and information on how environmental-related energy models assess environmental impacts, the paper aims at supporting further model development for integrated sustainability assessment of renewable energy options.

2. Methods

To get an overview of energy related models and their potential for integrated assessment, the research was carried out in three steps. Firstly, a literature review was conducted concerning modelling tools that are potentially useful for addressing energy policy and its environmental impacts in an integrated assessment. The questions posed in this review were:

- Which aspects have been concerned in energy models?
- Which aspects have been concerned in models addressing biodiversity and ecosystem services related to land use?
- Are there potential linkages between energy models and ecological assessment?

Secondly, a survey on energy related publications and their research scopes was performed through searches in the scientific literature database Scopus. In order to achieve a broad overview of publications on energy-related analysis within both energy and environment areas, we started by using all journal sources in Scopus and applying “energy model” as the keyword and “energy” and “environmental science” as research area limitation. Then, we narrowed down the sources to two selected journals, “Energy” and “Energy Policy”, which focus on energy-related publications, to specifically address the environmental-related research within energy analysis. For the analysis, the specific issues for environmental assessment defined in the EU SEA Directive were used as a checklist. The questions addressed in the second step were:

- How many energy-related publications in the whole database concerned climate change, land use, landscape and biodiversity, respectively?
- What is the situation in two energy-related journals?

Thirdly, the EU Energy Roadmap 2050 and its related impact analysis reports were reviewed. These were: A roadmap for moving to a competitive low carbon economy in 2050 [9]; Energy Roadmap 2050 [10]; Impact assessment—Energy Roadmap 2050[11]; Executive summary of the Impact assessment—Energy Roadmap 2050 [62]; and the Final report of the Advisory Group, Summary record of the PRIMES peer review meeting, Results of the public consultation on the Energy Roadmap 2050 [63]. As EUs biggest energy plan, the model-based analyses that were used in the EU Energy Roadmap 2050 were evaluated from the SEA perspective. Also for this analysis, the specific issues for environmental assessment defined in the EU SEA Directive were used as a checklist. The following questions were addressed during the review:

- What impacts were considered in the analyses of the EU Energy Roadmap 2050?
- What models were used for the impact analysis?
- What impacts that are covered by the SEA framework were not included or appropriately addressed in the EU Energy Roadmap 2050?

3. Results and discussion

3.1. Review of models addressing energy systems and environmental impacts

Energy system modelling tools have been widely developed and integrated with, for instance, economic models and to some extent with environmental models. To assess the models' scopes and the connections between them, we reviewed a selection of models which are widely used for scenario building and analysis in the context of EU (and other) energy policy and planning.

3.1.1. Models integrating energy and economic concerns

One group of models can be called *energy–economy models*. Among them, the model PRIMES has been used by EU for forecasting, scenario

construction and policy impact analysis up to the year 2050. It simulates market equilibrium for energy demand and supply within the European Union and it focuses on market-related mechanisms influencing the evolution of demand and supply [64]. TIMES is another example of an economic model generator for local, national or multi-regional energy systems [65].

3.1.2. Models integrating energy and emission concerns

The modelling scope is expanded within a group of models that can be called *energy–emission models*. For instance, GAINS (GHG-Air pollution Interaction and Synergies) has been used by EU for emission assessment of the six greenhouse gases covered under the Kyoto Protocol (CO_2, CH_4, N_2O and the three F-gases) together with the emissions of other air pollutants [9]. CAPRI (Common Agricultural Policy Regionalised Impact) models the response of the European agriculture system and environmental indicators involved are balances for N, P, and K; emissions of ammonia, methane and N_2O; GHG; and energy use in agriculture. In EU Energy Roadmap 2050, CAPRI, together with GAINS, was used for analysis of agricultural production and emissions [9]. GLOBIOM (Global Biomass Optimization Model) aims to analyse policy alternatives on global issues concerning land use competition between major land-based production sectors. In EU Energy Roadmap 2050, GLOBIOM was used together with the G4M model for analysis of wood demand, emission from forest and agricultural land and land use changes [9]. MAGICC (Model for the Assessment of Greenhouse Gas Induced Climate Change) is another example of a model that includes a carbon cycle model that relates atmospheric inputs (emissions) and outputs (physical and chemical sink processes) to changes in the atmospheric carbon concentration [66].

3.1.3. Models integrating energy and social concerns

Energy system analysis and social impacts can be linked in a group of models with a partly different scope that can be called *energy–social models*. Among them, GEM-E3 (General equilibrium model) has been used by EU for social impact analysis, specifically employment. It computes the equilibrium in the goods and services markets and determines separately the supply or demand of labour, capital, energy, and other goods [9]. The analysis also involved spatial models for land use analysis. Another of these models is G4M (Global Forest Model) that provides spatially explicit estimates of annual bio-mass increment, development of forest bio-mass and costs of forestry options such as forest management, afforestation and deforestation by comparing the income of alternative land uses [9].

3.1.4. Models integrating energy, technology, economy and emission concerns

There are also *models covering energy–technology–economy–emissions* issues. For instance, the POLES (Prospective Outlook on Long-term Energy Systems) model provides a tool for forecasting long-term energy, technology and climate change issues. It has been used for global energy demand and supply analysis [9]. Another of these models is the global optimization model MERGE (Model for Estimating the Regional and Global Effects) [67], which describes the interaction between macroeconomic production, the energy system (demand and supply), pollutant emissions, and climate change. Further, the ERIS (Energy Research and Investment Strategies) model was created to examine the effects of different representations of technological change in energy optimization models, focusing primarily on the electricity generation sector [68].

More a methodology than a specific model, the aim of LCA (Life-Cycle Assessment) is to calculate the environmental impacts and resource uses due to a product or service “from cradle to grave” [69]. Compared to the requirement for SEA established in the EU SEA Directive, the virtue of LCA is specifically that it aims to comprehensively describe the environmental impacts through a “functional unit” considered for a broad range of impact categories. A limitation of LCA pointed out by Finnveden et al. [51] is that LCA is a non-site specific, time-independent tool. As per their argumentation, in the inventory phase, the specific location and timing of resource extractions and of emissions to the environment are not included in the data sets used.

Furthermore, whilst LCA may provide quantitative, non-site specific, time independent information about environmental impacts due to physical material flows and chemical and physical processes, impacts due to land use are currently under development. Some efforts have been made to use LCA to assess the impacts of land use changes on biodiversity [70–73]. Still, Finnveden et al. [74] reasoned that whilst land use is included in life-cycle inventory, and assessed as an elementary flow in many LCA methods, there is no concensus as to how subsequent impacts due to land use, such as loss of biodiversity, loss of soil quality and loss of biotic production potential should be accounted for in LCA [74].

3.1.5. Models integrating energy and ecological concerns

Ecological assessment models for land use change and biodiversity response analysis have been established and broadly used for ecosystem impact analysis. Such spatial models address ecosystem processes on different levels; focusing on e.g. ecosystems distribution, fragmentation, rarity, etc. [75,76]; species and community distribution, diversity, abundance, rarity, habitat suitability and connectivity, etc. [52,77–82], or both [53,55,83]. Another approach is to model prioritised groups of species characterised by their ecological profiles [54,84,85]. These spatial ecological assessment models can further be used as sub-models to integrated assessment tools, where multiple criteria can be considered simultaneously, see e.g. [56,57,86–88]. The connection of ecological assessment models with energy models has not been as broad as the connection of energy models with economic and emission models in this literature review.

For integrated assessment of energy policy and planning, multiple and sometimes conflicting criteria need to be handled together and evaluated in decision-making. For this purpose, MCA (Multi-Criteria Analysis) methods have been widely used for handling e.g. environmental issues (e.g. [89]). Compared with single criteria approaches, MCA is designed to take complex factors into consideration and to perform an integrated analysis [58]. A multitude of tools have been developed to carry MCA analysis both in spatial (e.g. [90–93]) and non-spatial (e.g. [94–96]) approaches. MCA has been used for renewable energy system evaluation [97] and for energy policy design, especially for integrated energy and environmental policy strategies [98–100].

Another approach to link multiple criteria would be to translate all indicators into one “currency”, such as cost-benefit analysis. Economic valuation of biodiversity and ecosystem services has been seen as a promising approach to improve sustainable management and decision-making [101–105]. For energy related analyses, research on energy impacts on ecosystems using market-based ecosystem valuation methods can be found, but full economic valuation studies of such impacts are still lacking [106].

In sum, energy models are mainly analysing energy demand and supply, energy prices and costs, GHG emissions, air pollution and social impact on employment. Land use analysis in this context is scarce but development is on-going [5,9,51,107–110]. Renewable energy would have significant impact on land use, landscapes and biodiversity and the connection of those issues with energy systems, especially renewable energy systems, is

obvious but the linkage between ecological assessment models and energy models are rarely found according to the literature review.

3.2. Integrated energy–environmental analysis

The survey on publications on energy models in the Scopus database revealed the lopsidedness of energy-related environmental impact analysis. As shown in Fig. 2, energy related models are very much focusing on climate change issues compared with other environment issues. Specifically research about interactions between energy and biodiversity is weak. In the next step, the literature search source was narrowed down to two journals, “Energy” and “Energy Policy”, from which the results are illustrated in Fig. 3. As can be seen, energy model based research which is related to biodiversity is very scarce and seems to have started just in recent years. Landscapes seem to be a little more integrated while land use is increasingly being part of the analyses.

Regarding the target for GHG reduction set by EU, the EU Energy Roadmap 2050 [10] is, as mentioned, expected to support the shift towards a safe, resource efficient and sustainable low-carbon economy of EU. When reviewing the EU Energy Roadmap 2050 and its related impact assessment reports, concerning which impacts were analysed, what modelling tools were used and what were the targeted issues respectively, the results were summarized in Table 1.

By combining the results of all three reviews it was found that currently energy analysis and energy related environmental impact analysis are focusing mainly on climate factors. Looking into a single model, it could be seen that most of the now-existing energy models for policy assessment in one way or another focus on a single or a few issues, and on the other hand, the concerns about climate change and energy security are spurs for most of the models to focus on economy and GHG emission topics. According to the literature review, these two issues were dominating, while land use and biodiversity issues were largely neglected.

When comparing these results with the SEA environmental issues (biodiversity, population, human health, soil, water, air, climatic factors, material assets, cultural heritage, and landscape), it could be concluded that among the issues that has been pointed out as most urgent and at highest risk of being negatively affected by renewable energy options, biodiversity has to a large extent been neglected, while landscape issues has received slightly more attention. Land use is more common to take into account but the full potential of its connection with other environmental issues, among these biodiversity and landscape, cannot be considered to be reached. Thus, research and modelling concerning energy and environmental issues are still very isolated from each other. As a

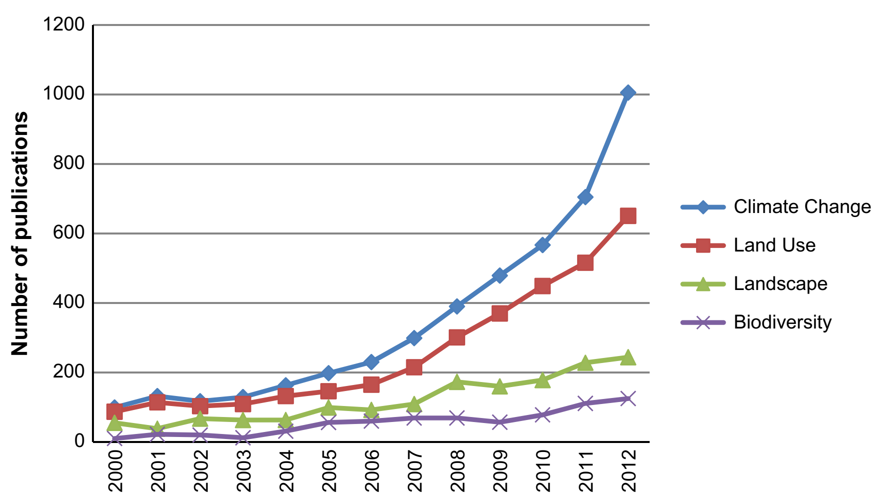
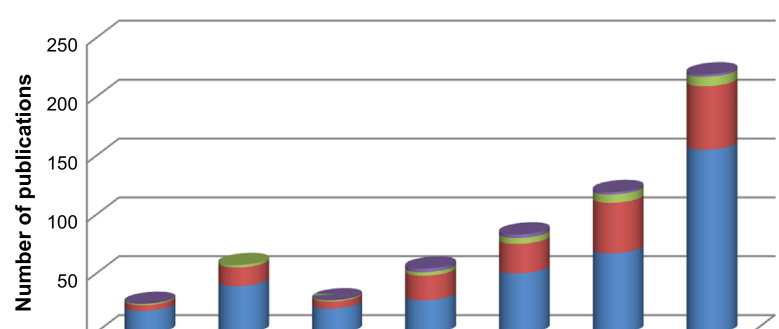


Fig. 2. Number of energy-model related publications found in the Scopus database.



	2006	2007	2008	2009	2010	2011	2012
Biodiversity	0	0	0	3	3	2	2
Landscape	1	2	1	3	5	7	8
Land use	5	16	6	21	25	43	54
Climate change	19	40	21	28	51	68	156

Fig. 3. Energy-model related publications found in the two energy-related journals *Energy* and *Energy Policy*.

Table 1
Summary of models and their targeting issues in EU Energy Roadmap 2050.

Impact analysis		Global Level	EU Level
Quantitatively			
Economic impacts	Energy price	POLES	PRIMES
	ETS carbon price	POLES	PRIMES GAINS
	Macro-economic impacts	GEM-E3	GEM-E3
	Investments and fuel expenses	–	PRIMES GAINS
Energy demand and supply	Oil production	POLES	–
	Energy consumption	–	PRIMES
	Imports of oil and gas	–	PRIMES
	Biomass production	–	PRIMES
	Energy-wood demand	–	PRIMES G4M GLOBIOM
Climate change impacts	CO_2 emission from energy and industrial sectors	POLES	PRIMES GAINS
	CO_2 emission from transport sector	–	PRIMES GAINS
	CO_2 emissions from agriculture	GLOBIOM G4M	–
	CO_2 emissions from forestry	GLOBIOM G4M	–
	CO_2 emission from land use change	–	GLOBIOM G4M
	Non-CO_2 emissions	–	GAINS CAPRI
Environmental impacts	Air pollution	–	GAINS
Social impacts	Security of supply—import dependency	–	PRIMES
	Energy related expenditure per households	–	PRIMES GAINS
	Employment/jobs	GEM E3	GEM E3
Qualitatively			
Environmental impacts	Land use	–	–
	Biodiversity	–	–
	Water use	–	–
Social impacts	Quality of jobs	–	–
	Safety and public acceptance	–	–

consequence of the fragmentation and lopsidedness of existing energy–environment models, a comprehensive analysis for policy assessment and decision making will be difficult to reach.

3.3. Final discussion

The top impact analysis topics in the EU energy roadmap 2050 were GHG emission reduction and energy supply, and renewable energy has been hotly debated. Renewable energy policies which could provide a great contribution to fulfil the climatic and energy security commitments might have significant negative environmental impacts especially concerning land use and its relation to biodiversity and landscapes. Impacts have been analysed as reported in the EU energy impact assessment documents, but in a quite different sense. GHG emission and economy factors were quantitatively evaluated by the help of energy models, while other issues were qualitatively analysed or roughly mentioned. Biodiversity, landscape and land use cannot be considered to be properly addressed although they are closely related to renewable energy issues and at the same time they are crucial indicators for sustainable development. One of the reasons could be the missing support from policy analysis tools and research. Such difficulties were revealed when reviewing publications on seemingly relevant models. Unlike the linking between energy and climate change, models for energy system analysis and models for ecological system analysis were quite isolated from each other and not very well integrated. Thus, to achieve a comprehensive policy assessment, there is a great need for an analysis framework and model integration which can fully cover crucial environmental factors, especially biodiversity, landscape and related land use issues.

SEA provides a conceptual framework for providing integrated analysis for promoting a sustainable development. SEA is as a systematic process for evaluating the environmental consequences of a proposed policy, plan and programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision making on par with economic and social considerations [111]. The benefits of SEA to an energy organization's operations can be seen in Jay's research about SEA for energy production [112]. The author stated that the need for SEA is greatest within the energy sector, not only for GHG emission issues but also to other long-standing environmental concerns, such as landscape issues.

SEA is defined to integrate environmental consequences into decision making processes of policies, plans or programmes but it is applied differently in different states and regions. In the legal framework of European Union Directive 2001/42/EC, SEA is limited to assessments of plans and programmes carried out by the public sectors in EU member states. By contrast, in Canada and South Africa, the scope of application covers all kinds of policies, plans and programs. A study of the UK, which aimed to be a ‘world leader in SEA’ by legislating for SEA to be undertaken of all public sector policies, plans, programmes, finds out that engagement with the SEA process is not as widespread as intended [113]. In line with this, it has been suggested that SEA should be applied both at a broad policy level and in the planning of new capacity, especially for renewable energy [111].

If they could be well integrated with ecological assessment models, current existing energy models which involve environmental, social and economic analyses could be used as tools for SEA and have great potential for comprehensive assessment of policies, plans and programs. One innovative approach to integrate spatial models into bioenergy systems was reported by Schardinger et al. [114]. It included agricultural and forestry process chains into an energy system model, with focus on land use for biomass production, aiming to evaluate the demands for energy, food and materials.

One approach embrace spatial models, which provide geographic input data and can cover regional energy demand and biomass potential for optimization analysis [115]. Another example of model connecting attempts concerns coupling Geographic Information Systems (GIS) and LCA for biodiversity assessment of land use [27]. GIS modelling was used to generate crop production scenarios for corn and sugar beets that meet a range of ethanol production targets. The resulting land use maps were translated into maps of habitat types, and treated as elementary input flows that could be expressed within the conventional structure of LCA methodology.

MCA is another example that could combine isolated modelling and research works and deliver quantitative and integrated environmental impact analysis which covers climate changes, land use changes, landscapes, biodiversity, and air pollution and other environmental issues. For SEA, the specified environmental issues could provide the multiple criteria for the MCA. Sustainability can then be evaluated by combining the criteria in different ways, such as by use of weighted linear combination or other methods [92,93,96].

4. Conclusion

When combining the results from the reviews, it was found that currently, energy analysis and energy related environmental impact assessment are focusing mainly on climate issues. Looking at a single model, it can be seen that most of the now-existing energy models for policy assessment in one way or another focus on a single or a few issues, and on the other hand, the concerns on climate change and energy security are spurs for most of the models to focus on economy and GHG emission topics. One can also see from the publications that these issues are dominating, while biodiversity and landscape issues and their relation to land use are largely neglected, even though ecological assessment models and linking methods exist. Models assessing energy and environmental issues are still to a large extent isolated from each other. A consequence of the fragmentation and lopsidedness of existing energy–environment models is that a comprehensive analysis for policy assessment and decision making will be difficult to reach. If energy models which have concerns on emissions and social impacts could also incorporate ecological assessment models, these could have great potential as tools for SEA for policy assessment as well as for planning, in EU and beyond.

Thus, to a large extent, energy models and ecological assessment models are working separately, leading to an energy–environmental assessment gap since renewables do affect biodiversity and landscapes. Connections between renewable energy and its impacts on air, climate, biodiversity and landscapes is still missing which leads to unnecessarily narrow scopes of policy assessment of important scenarios for future directions of energy systems in general and renewable energy in particular. A higher level of integration between assessment tools are needed for comprehensive energy–environmental assessment of renewable energy options, avoiding intrinsic goal conflicts between policy objectives and to find sustainable solutions for future energy systems.

Acknowledgement

The research was supported by the Swedish strategic research programme StandUp for Energy.

References

[1] Banse M, van Meijl H, Tabeau A, Woltjer G, Hellmann F, Verburg PH. Impact of EU biofuel policies on world agricultural production and land use. Biomass Bioenergy 2011;35:2385–90.
[2] Bentsen NS, Felby C. Biomass for energy in the European Union—a review of bioenergy resource assessments. Biotechnol Biofuels 2012;5:25.
[3] Dijkman TJ, Benders RMJ. Comparison of renewable fuels based on their land use using energy densities. Renew Sustain Energy Rev 2010;14:3148–55.
[4] Havlík P, Schneider UA, Schmid E, Böttcher H, Fritz S, Skalský R, et al. Global land-use implications of first and second generation biofuel targets. Energy Policy 2011;39:5690–702.
[5] Leal MRLV, Horta Nogueira LA. Cortez LAB: land demand for ethanol production. Appl Energy 2014;102:266–71.
[6] Dale V, Efroymson R, Kline K. The land use—climate change—energy nexus. Landsc Ecol 2011;26:755–73.
[7] Rockström J, Steffen W, Noone K, Persson Å, Chapin III FS, Lambin E, et al. A safe operating space for humanity. Nature 2009;461:472–5.
[8] Convention on Biological Diversity 2010. Decisions adopted by the Conference of the Parties to the CBD at its Tenth Meeting, Nagoya. Available at ⟨www.cbd.int⟩; 2010 [accessed 1.11.12].
[9] European Commission 2011a. Communication from the Commission to the European parliament, the Council, the European Economic and social committee and the Committee of the regions: a roadmap for moving to a competitive low-carbon economy in 2050, European commission SEC (2011) 288 final.
[10] European Commission 2011b. Communication from the Commission to the European parliament, the Council, the European Economic and social committee and the committee of the regions: energy roadmap 2050, European commission COM (2011) 885 final.
[11] European Commission 2011c. Communication from the Commission to the European parliament, the Council, the European economic and social committee and the committee of the regions: impact assessment—energy roadmap 2050, European commission SEC (2011) 1565 final.
[12] International Energy Agency. World energy outlook 2011. International Energy Agency; 2011.
[13] Lovich JE, Ennen JR. Assessing the state of knowledge of utility-scale wind energy development and operation on non-volant terrestrial and marine wildlife. Appl Energy 2013;103:52–60.
[14] Baerwald EF, D'Amours GH, Klug BJ, Barclay RMR. Barotrauma is a significant cause of bat fatalities at wind turbines. Curr Biol 2008;18:R695–6.
[15] Drewitt AL, Langston RHW. Assess Impacts of Wind Farms Birds, Ibis 2006;148:29–42.
[16] Kikuchi R. Adverse impacts of wind power generation on collision behavior of birds and anti-predator behavior of squirrels. J Nat Conserv 2008;16:44–55.
[17] Kuvlesky WP, Brennan Jr LA, Morrison ML, Boydston KK, Ballard BM, Bryant FC. Wind energy development and wildlife conservation: challenges and opportunities. J Wildlife Manag 2007;77:2487–98.
[18] Tabassum A, Premalatha M, Abbasi T, Abbasi SA. Wind energy: increasing deployment, rising environmental concerns. Renew and Sustain Energy Rev 2014;31:270–88.
[19] Fthenakis V, Blunden J, Green T, Krueger L, Turney D. 2011. Large photovoltaic power plants: wildlife impacts and benefits. Conference Record of the IEEE photovoltaic specialists conference, art. no. 6186348, p. 002011–16.
[20] Lovich JE, Ennen JR. Wildlife conservation and solar energy development in the Desert Southwest. BioScience 2011;61:982–92.
[21] Torcellini P, Long N, Judkoff R. Consumptive water use for U.S. power production. ASHRAE Trans 2004;110(Part 1):96–100.
[22] Tsoutsos T, Frantzeskaki N, Gekas V. Environmental impacts from solar energy technologies. Energy Policy 2005;33:289–96.
[23] Felten D, Fröba N, Fries J, Emmerling C. Energy balances and greenhouse gas-mitigation potentials of bioenergy cropping systems (Miscanthus, rapeseed, and maize) based on farming conditions in Western Germany. Renew Energy 2013;55:160–74.
[24] Borrion AL, McManus MC, Hammond GP. Environmental life cycle assessment of lignocellulosic conversion to ethanol: a review. Renew Sustain Energy Rev 2012;16:4638–50.
[25] De Vries JW, TMWJ Vinken, Hamelin L, De Boer IJM. Comparing environmental consequences of anaerobic mono- and co-digestion of pig manure to produce bio-energy—a life cycle perspective. Bioresour Technol 2012;125:239–48.
[26] Danielsen F, Beukema H, Burgess ND, Parish F, BrÜhl CA, Donald PF, et al. Biofuel plantations on forested lands: double jeopardy for biodiversity and climate. Conserv Biol 2009;23:348–58.
[27] Geyer R, Lindner JP, Stoms DM, Davis FW, Wittstock B. Coupling GIS and LCA for biodiversity assessments of land use. Int J Life Cycle Assess 2010;15:454–67.

[28] Pedroli B, Elbersen B, Frederiksen P, Grandin U, Heikkilä R, Krogh PH, et al. Is energy cropping in Europe compatible with biodiversity?—opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes Biomass Bioenergy 2013;55:73–86.
[29] Gasparatos A, Stromberg P, Takeuchi K. Biofuels, ecosystem services and human wellbeing: putting biofuels in the ecosystem services narrative. Agric Ecosyst Environ 2011;142:111–28.
[30] Ciccarese L, Mattsson A, Pettenella D. Ecosystem services from forest restoration: thinking ahead. New Forests 2012;43:543–60.
[31] Norris K. Biodiversity in the context of ecosystem services: the applied need for systems approaches. Philos Trans R Soc B: Biol Sci 2012;367:191–9.
[32] Verschuyl J, Riffell S, Miller D, Wigley TB. Biodiversity response to intensive biomass production from forest thinning in North American forests—a meta-analysis. Forest Ecol Manag 2011;261:221–32.
[33] Gonzalez-Garcia S, Moreira MT, Feijoo G. Environmental performance of lignocellulosic bioethanol production from Alfalfa stems. Biofuels Bioprod Biorefin 2010;4:118–31.
[34] Gonzalez-Garcia S, Gasol CM, Gabarrell X, Rieradevall J, Moreira MT, Feijoo G. Environmental profile of ethanol from poplar biomass as transport fuel in Southern Europe. Renew Energy 2010;35:1014–23.
[35] Luo L, van der Voet E, Huppes G, Udo de Haes HA. Allocation issues in LCA methodology: a case study of corn stover-based fuel ethanol. Int J Life Cycle Assess 2009;14:529–39.
[36] Smil V. Energy at the cross roads: global perspectives and uncertainties. Cambridge, Massachusetts, London, England: The MIT Press; 2003; 249–51.
[37] Zhang Q, Li L, Wang Y-G, Werner AD, Xin P, Jiang T, et al. Has the Three-Gorges Dam made the Poyang Lake wetlands wetter and drier? Geophys Res Lett 2012;39:1–7 (article no. L20402).
[38] Kunz MJ, Wüest A, Wehrli B, Landert J, Senn DB. Impact of a large tropical reservoir on riverine transport of sediment, carbon, and nutrients to downstream wetlands. Water Resour Res 2011;47:1–16 (article no. W12531).
[39] ARCADIS. Hydropower Generation in the context of the EU WFD. Available at 〈www.arcadisbelgium.be〉; 2011.
[40] Delucchi M. A conceptual framework for estimating the climate impacts of land-use change due to energy crop programs. Biomass Bioenergy 2011;35:2337–60.
[41] Hellmann F, Verburg PH. Impact assessment of the European biofuel directive on land use and biodiversity. J Environ Manag 2010;91:1389–96.
[42] Riffell S, Verschuyl J, Miller D, Wigley TB. Biofuel harvests, coarse woody debris, and biodiversity—a meta-analysis. Forest Ecol Manag 2011;261:878–87.
[43] Fischer TB. Theory and practice of strategic environmental assessment. London: Earthscan; 2007.
[44] Ahmed K, Sánchez-Triana E. Strategic environmental assessment for policies: an instrument for good governance. Washington DC: World Bank; 2008 (License: Creative Commons Attribution CC BY 3.0).
[45] Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, van Vuuren Detlef P, et al. The next generation of scenarios for climate change research and assessment. Nature 2010;463:747–56.
[46] Wagner F, Heyes C, Klimont Z, Schoepp W.. The GAINS optimization module: identifying cost-effective measures for improving air quality and short-term climate forcing. IIASA Interim Report IR-13-001, 2013.
[47] Klimont Z, Smith SJ, Cofala J. The last decade of global anthropogenic sulfur dioxide: 2000–2011 emissions. Environ Res Lett 2013;8:01400.
[48] Reis S, Grennfelt P, Klimont Z, Amann M, ApSimon H, Hettelingh J-P, et al. From acid rain to climate change. Science 2012;338:1153–4.
[49] Fragkos P, Kouvaritakis N, Capros P. Model-based analysis of the future strategies for the MENA energy system. Energy Strategy Rev 2013;2:59–70.
[50] Stow M, McManus MC, Bannister C. A life cycle assessment comparison of rapeseed biodiesel and conventional diesel. Inst Mech Eng—Sustain Vehicle Technol: Driv Green Agenda 2012:23–33.
[51] Finnveden G, Nilsson M, Johansson J, Persson Å, Moberg Å, Carlsson T. Strategic environmental assessment methodologies—applications within the energy sector. Environ Impact Assess Rev 2003;23:91–123.
[52] Mörtberg U, Balfors B, Knol WC. Landscape ecological assessment: a tool for integrating biodiversity issues in strategic environmental assessment and planning. J Environ Manag 2007;82:457–70.
[53] Gontier M, Balfors B, Mörtberg U. Biodiversity in environmental assessment: current practice and tools for prediction. Environ Impact Assess Rev 2006;26:268–86.
[54] Zetterberg A, Mörtberg U, Balfors B. Making graph theory operational for landscape ecological assessments, planning, and design. Landsc Urban Plann 2010;95:181–91.
[55] Alkemade R, Van Oorschot M, Miles L, Nellemann C, Bakkenes M, Ten Brink B. GLOBIO3: a framework to investigate options for reducing global terrestrial biodiversity loss. Ecosystems 2009;12:374–90.
[56] Segan DB, Game ET, Watts ME, Stewart RR, Possingham HP. An interoperable decision support tool for conservation planning. Environ Model Softw 2011;26:1434–41.
[57] González del Campo A. GIS in environmental assessment: a review of current issues and future needs. J Environ Assess Policy Manag 2012;14:1250007.
[58] Wang JJ, Jing YY, Zhang CF, Zhao JH. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sustain Energy Rev 2009;13:2263–78.
[59] Afgan NH, Carvalho MG. Multi-criteria assessment of new and renewable energy power plants. Energy 2002;27:739–55.
[60] Broughton EK, Brent AC, Haywood L. Application of a multi-criteria analysis approach for decision-making in the energy sector: the case of concentrating solar power in South Africa. Energy Environ 2012;23:1221–31.
[61] Gounaridis D, Zaimes GN. GIS-based multicriteria decision analysis applied for environmental issues; the Greek experience. Int J Appl Environ Sci 2012;7:307–21.
[62] European Commission 2011d. Communication from the commission to the European parliament, the Council, the European economic and social committee and the committee of the regions: executive summary of the impact assessment—Energy roadmap 2050, European Commission SEC (2011) 1566 final.
[63] European Commission 2011e. Final report of the advisory group, Summary record of the PRIMES Peer review meeting, Results of the public consultation on the Energy Roadmap 2050. European commission 2011. Communication from the commission to the european parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy roadmap 2050. European commission SEC (2011) 1569 final.
[64] E3Lab of the National Technical University of Athens, 〈http://www.e3mlab.ntua.gr/e3mlab/index.php〉.
[65] Loulou R, Labriet M. 2007. ETSAP-TIAM: the TIMES integrated assessment Springe.
[66] Riahi K, Roehrl RA. Greenhouse gas emissions in a dynamics-as-usual scenarios of economic and energy development. Technol Forecast Soc Change 2000;63:175–206.
[67] Manne A, Richels R. 2004. MERGE: a model for evaluating the regional and global effects of GHG reduction policies, 〈http://www.stanford.edu/group/MERGE/〉.
[68] Barreto L, Kypreos S. Endogenizing R&D and market experience in the "bottom-up" energy-systems ERIS model. Technovation 2004;24:615–29.
[69] Bjorklund A. Life cycle assessment as an analytical tool in strategic environmental assessment. Lessons learned from a case study on municipal energy planning in Sweden. Environ Impact Assess Rev 2012;32:82–7.
[70] Lindeijer E. Biodiversity and life support impacts of land use in LCA. J Clean Prod 2000;8:313–9.
[71] Koellner T, Scholz RW. Assessment of land use impacts on the natural environment: Part 1: an analytical framework for pure land occupation and land use change. Int J Life Cycle Assess 2007;12:16–23.
[72] Koellner T, Scholz RW. Assessment of land use impacts on the natural environment: Part 2: generic characterization factors for local species diversity in Central Europe. Int J Life Cycle Assess 2008;13:32–48.
[73] Michelsen O. Assessment of land use impact on biodiversity: proposal of a new methodology exemplified with forestry operations in Norway. Int J Life Cycle Assess 2008;13:22–31.
[74] Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, et al. Recent developments in Life Cycle Assessment. J Environ Manag 2009;91:1–21.
[75] Geneletti D. Using spatial indicators and value functions to assess ecosystem fragmentation caused by linear infrastructures. Int J Appl Earth Obs Geoinf 2004;5:1–15.
[76] Cushman SA, McGarigal K, Neel MC. Parsimony in landscape metrics: strength, universality, and consistency. Ecol Indic 2008;8:691–703.
[77] Phillips SJ, Miroslav D. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 2008;31:161–75.
[78] Anderson RP, Lew D, Peterson AT. Evaluating predictive models of species' distributions: criteria for selecting optimal models. Ecol Model 2003;162:211–32.
[79] Drielsma M, Ferrier S. Rapid evaluation of metapopulation persistence in highly variegated landscapes. Biol Conserv 2009;142:529–40.
[80] Gontier M, Mörtberg U, Balfors B. Comparing GIS-based habitat models for applications in EIA and SEA. Environ Impact Assess Rev 2010;30:8–18.
[81] Bacaro G, Rocchini D, Ghisla A, Marcatonio M, Neteler M, Chiarucci A. The spatial domain matters: spatially constrained species rarefaction in a Free and Open Source environment. Ecol Complex 2012;12:63–9.
[82] Chiarucci A, Bacaro G, Scheiner SM. Old and new challenges in using species diversity for assessing biodiversity. Philos Trans R Soc B 2011;366:2426–37.
[83] Di Minin E, Moilanen A. Empirical evidence for reduced protection levels across biodiversity features from target-based conservation planning. Biol Conserv 2012;153:187–91.
[84] Vos CC, Verboom J, Opdam PFM, Ter Braak CJF. Toward Ecologically Scaled Landscape Indices. Am Nat 2001;157:24–41.
[85] Mörtberg U, Zetterberg A, Balfors B. Urban landscapes in transition—lessons from integrating biodiversity and habitat modelling in planning. J Environ Assess Policy Manag 2012;14:1–31.
[86] Coutinho-Rodrigues J, Simão A, Antunes CH. A GIS-based multicriteria spatial decision support system for planning urban infrastructures. Decis Support Syst 2011;51:720–6.
[87] Scolozzi R, Geneletti D. A multi-scale qualitative approach to assess the impact of urbanization on natural habitats and their connectivity. Environ Impact Assess Rev 2012;36:9–22.
[88] Bottero M, Comino E, Duriavig M, Ferretti V, Pomarico S. The application of a multicriteria spatial decision support system (MCSDSS) for the assessment of biodiversity conservation in the Province of Varese (Italy). Land Use Policy 2013;30:730–8.
[89] Huang IB, Jeffrey K, Igor L. Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. Sci Total Environ 2011;409:3578–94.

[90] Bagli S, Geneletti D, Orsi F. Routeing of power lines through least-cost path analysis and multicriteria evaluation to minimise environmental impacts. Environ Impact Assess Rev 2011;31:234–9.
[91] Hott R, Santini R, Brownson J. 2012. GIS-based spatial analysis for large-scale solar power and transmission line issues: case study of Wyoming, U.S., World Renewable Energy Forum, WREF 2012, Including World Renewable Energy Congress XII and Colorado Renewable Energy Society (CRES) Annual Conference vol. 3: p. 2274–9.
[92] Geneletti D. Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. Waste Manag 2010;30:328–37.
[93] Orsi F, Geneletti D. Identifying priority areas for Forest Landscape Restoration in Chiapas (Mexico): an operational approach combining ecological and socioeconomic criteria. Landsc Urban Plann 2010;94:20–30.
[94] Browne D, O'Regan B, Moles R. Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region. Energy 2010;35:518–28.
[95] González A, Donnelly A, Jones M, Chrysoulakis N, Lopes M. A decision-support system for sustainable urban metabolism in Europe. Environ Impact Assess Rev 2013;38:109–19.
[96] Munda G, Russi D. Social multicriteria evaluation of conflict over rural electrification and solar energy in Spain. Environ Plann C: Gov Policy 2008;26:712–27.
[97] Mamlook R, Akash BA, Nijmeh S. Fuzzy sets programming to perform evaluation of solar systems in Jordan. Energy Convers Manag 2001;42:1717–26.
[98] Kablan MM. Decision support for energy conservation promotion: an analytic hierarchy process approach. Energy Policy 2004;32:1151–8.
[99] Greening LA, Bernow S. Design of coordinated energy and environmental policies: use of multi-criteria decision-making. Energy Policy 2004;32:721–35.
[100] Diakoulaki D, Zopounidis C, Mavrotas G, Doumpos M. The use of a preference disaggregation method in energy analysis and policy making. Energy 1999;24:157–66.
[101] Helm D, Hepburn C. The economic analysis of biodiversity: an assessment. Oxf Rev Econ Policy 2012;28:1–21.
[102] Laurans Y, Pascal N, Binet T, Brander L, Clua E, David G, et al. Economic valuation of ecosystem services from coral reefs in the South Pacific: taking stock of recent experience. J Environ Manag 2013;116:135–44.
[103] Gómez-Baggethun E, Barton DN. Classifying and valuing ecosystem services for urban planning. Ecol Econ 2013;86:235–45.
[104] Maes J, Hauck J, Paracchini ML, Ratamäki O, Hutchins M, Termansen M, et al. Mainstreaming ecosystem services into EU policy. Curr Opin Environ Sustain 2013;5:128–34.
[105] Zhao M, Johnston RJ, Schultz ET. What to value and how? Ecological indicator choices in stated preference valuation Environ Resource Econ 2013;56:3–25.
[106] Mangi SC. The impact of offshore wind farms on marine ecosystems: a review taking an ecosystem services perspective. Proc IEEE 2013;101:999–1009.
[107] Affuso E, Hite D. A model for sustainable land use in biofuel production: an application to the state of Alabama. Energy Econ 2013;37:29–39.
[108] Böttcher H, Frank S, Havlík P, Elbersen B. Future GHG emissions more efficiently controlled by land-use policies than by bioenergy sustainability criteria. Biofuels Bioprod Biorefin 2013;7:115–25.
[109] Mellino S, Ripa M, Zucaro A, Ulgiati S. An emergy-GIS approach to the evaluation of renewable resource flows: a case study of Campania Region, Italy. Ecol Model 2014;271:103–12.
[110] Scarlat N, Dallemand J-F, Banja M. Possible impact of 2020 bioenergy targets on European Union land use. A scenario-based assessment from national renewable energy action plans proposals. Renew Sustain Energy Rev 2013;18:595–606.
[111] Sadler B, Verheem R. 1996. SEA: status, challenges and future directions. Report 53, Ministry of housing, Spatial planing and the environment.
[112] Jay S. Strategic environmental assessment for energy production. Energy Policy 2010;38:3489–97.
[113] McLauchlan A, João E. The inherent tensions arising from attempting to carry out strategic environmental assessments on all policies, plans and programmes. Environ Impact Assess Rev 2012;36:23–33.
[114] Schardinger I, Botzenhart F, Biberacher M, Hamacher T, Blaschke T. Integrating spatial models into regional energy system optimisation: focusing on biomass. Int J Energy Sect Manag 2012;6:5–32.
[115] Thomas A, Bond A, Hiscock KA. GIS based assessment of bioenergy potential in England within existing energy systems. Biomass Bioenergy 2013;55:107–21.